Wu, Peng, Xia, Bo, Pienaar, Josua, & Zhao, Xianbo
(2014)
The past, present and future of carbon labelling for construction materials – a review.
Building and Environment, *77*, pp. 160-168.

The past, present and future of carbon labelling for construction materials – a review

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Abstract

Global climate change is one of the most significant environmental issues that can harm human development. One central issue for the building and construction industry to address global climate change is the development of a credible and meaningful way to measure greenhouse gas (GHG) emissions. While Publicly Available Specification (PAS) 2050, the first international GHG standard, has been proven to be successful in standardizing the quantification process, its contribution to the management of carbon labels for construction materials is limited. With the recent publication of ISO 14067: *Greenhouse gases – carbon footprint of products – requirements and guidelines for quantification and communication* in May 2013, it is necessary for the building and construction industry to understand the past, present and future of the carbon labelling practices for construction materials. A systematic review shows that international GHG standards have been evolving in terms of providing additional guidance on communication and comparison, as well as less flexibility on the use of carbon labels. At the same time, carbon labelling schemes have been evolving on standardization and benchmarking. In addition, future actions are needed in the aspect of raising consumer awareness, providing benchmarking, ensuring standardization and developing simulation technologies in order for carbon labelling schemes for construction materials to provide credible, accurate and transparent information on GHG emissions.

Keywords: International GHG standards; Carbon labels; Global climate change; Greenhouse gas emissions; Construction materials.

1. Introduction

Environmental issues seem to be one of the most significant pressures for human development at the moment. The United Nations Environment Programme's GEO-4 Report (UNEP, 2007) reported that around half of the world's rivers are seriously polluted and depletion of ozone layer has reached record levels. Billions of people are exposed to natural disaster risks, including weather-related disasters that take lives, damage infrastructure and natural resources, and disrupt economic activities (Pelling et al., 2004).

Of all environmental issues, global climate change seems to be the most significant one. It is caused by concentrations of greenhouse gases (GHGs) such as carbon dioxide, methane and nitrous oxide. Concentrations of carbon dioxide stood at 396 ppm (parts per million) in December 2013 (Mauna Loa Observatory, 2013). The 396 ppm far exceeds the pre-industrial (18^{th} century) level of 280 ppm. The impact of global climate change can be catastrophic. Global average sea level has risen since 1960 at an average rate of 1.8mm/year and since 1993 at 3.1mm/year (Intergovernmental Panel on Climate Change, 2007). The worst-case predictions for rising sea levels in the Thames Estuary would see the level of the river rising by up to four metres by 2100, which means that eventually, large parts of London – one of the world's business capitals – would be under water (Tang and Yeoh, 2007). According to the Australian Department of the Environment (2014), human-induced global warming was a key reason why the Australian drought of 2002 was so severe. In addition, the U.S. Environmental Protection Agency (2013) reported that global climate change would have a significant impact on crop yields, livestock and fisheries. If actions were not taken to reduce GHG emissions, the overall costs and risks of climate change would be equivalent to losing at least 5% of global GDP per year, now and forever (Stern, 2007).

The building and construction industry contributes to global climate change in its life cycle. Extraction and manufacturing of raw materials generate a significant amount of GHG emissions (Worrell et al., 2001a). The cement section alone accounts for 5% of global man-made CO_2 emissions (Worrell et al., 2001b). Transportation of raw materials is also energy intensive, especially for countries which relies heavily on import of raw materials (Wu and Low, 2011). On-site construction of building is not always effective and may generate unnecessary carbon emissions (Wu and Low, 2012; Wu and Low, 2013). As one of the largest sources of GHG emissions, the building and construction industry is facing increasing pressure to reduce its life cycle GHG emissions.

One central issue in striving towards reduced carbon emissions is to develop a practical and meaningful yardstick to assess and communicate GHG results (Crawley and Aho, 1999). According to Ball (2002), there is a strong interest within the construction industry for well respected schemes for product labelling and performance standards. Thus, a number of international GHG standards and carbon labelling programs have already been initiated. The most commonly recognized international GHG standards include Public Available Specification

(PAS) 2050: *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services* (published by the British Standards Institution in 2008), World Resource Institute / World Business Council for Sustainable Development (WRI/WBCSD): *Product life cycle accounting and reporting standard* (hereafter referred to as The GHG Protocol) (jointly published by WRI and WBCSD in 2011) and ISO 14067: *Greenhouse gases – carbon footprint of products – requirements and guidelines for quantification and communication* (published by International Organization for Standardization in 2013). At the same time, internationally recognized carbon labelling schemes include the Singapore Green Labelling Scheme (SGLS), the CO_2 Measured Label and the Reducing CO_2 Label (previously known as the Carbon Label and the Carbon Reduction Label developed by Carbon Trust in UK), the CarbonCounted (Canada), the CarbonFree (US) and the Hong Kong Carbon Labelling Scheme (CLS). These internationally recognized GHG standards and carbon labelling schemes make a significant contribution to the assessment and communication of GHG emissions either in a business-to-business or a business-to-customer way. It is expected that by adopting the GHG standards and promoting the use of carbon labels in the building and construction industry, consumer behaviour can be changed so that low-carbon products will be preferred.

However, both GHG standards and carbon labelling schemes have been evolving and will continue to evolve in the future. For example, new assessment and communication principles are proposed in the recently published ISO 14067. Understanding the development of carbon labelling practices can be generally seen as the first step for the building and construction industry to cope with the evolution. This paper therefore aims to examine the development of carbon labelling practices, consisting of international GHG standards and carbon labelling schemes, in the building and construction industry. Based on the development, a research agenda for the future in the area of carbon labelling is identified.

2. Environmental labelling schemes and carbon labelling schemes

Environmental labelling or ecolabelling is developed based on growing concerns on environmental protection. It aims to identify products with superior environmental performance and to stimulate environmental concern in product development (Jönsson, 2000). It can help companies to integrate environmental management activities into corporate sustainability performance measurement and reporting initiatives (Papadopoulos and Giama, 2007). The world's first environmental labelling scheme, i.e. the Blue Angel, was developed in Germany in 1978 to be used as a market-conform instrument to distinguish the positive environmental features of products and services on a voluntary basis (Blue Angel, 2013). The basic award criteria in the Blue Angel included environment and health, climate, water, and resources. Environmental labelling was identified as one of the most significant themes in Agenda 21 at the United Nations Conference on Environment and Development in 1992, which clearly stated that governments should encourage the use of environmental labelling to assist consumers to make informed choices (United Nations Sustainable Development, 1992).

Environmental labelling programs may provide one or several pieces of environment-related information, such as modelling energy consumption, water consumption, carbon emissions and wastes. These pieces of information are aggregated into a single score for making decisions relating to the selection of materials, products or services. In the building and construction industry, ecolabelling programs can be used to assess the whole building performance as well as the performance of construction materials. According to Trusty (2001), depending on the coverage, life cycle assessment tools, which are commonly adopted in ecolabelling programs, can be divided into three levels, which are:

- Level 1: Product comparison tools (e.g. UK Ecopoints, Blue Angel, NF Environment Mark)
- Level 2: Whole building design or decision support tool (e.g. Whole Life Cycle Costing, Multi-Criteria Decision Making)
- Level 3: Whole building assessment frameworks (BREEAM, LEED, Green Globes)

Carbon labelling schemes for construction materials are designed to help the construction industry to mitigate the impacts of global climate change and are therefore Level 1 product comparison tools. The whole labelling process consists of estimating the inputs of raw materials, energy and others, as well as the outputs of emissions to air with the manufacture of a product, operation of a process or provision of a service.

In a similar way, the International Organization for Standardization established three types of environmental labelling, which are:

- Type I: Type I refers to ecolabelling schemes which award a mark or logo based on the fulfilment of a set of criteria (ISO 14024, 1999).
- Type II: Type II refers to environmental claims which are self-declared by manufacturers and businesses (ISO 14021, 1999).
- Type III: Type III refers to ecolabelling schemes which provide life-cycle data declarations for the products. (ISO 14025, 2006).

Generally speaking, all carbon labelling schemes are single-issue type III environmental declarations which extract the information related to GHG emissions to become a climate declaration. Although carbon labelling schemes focus on a specific category (i.e. climate change), as Type III environmental declarations, they are based on the same life cycle assessment principles, including ISO 14040 (2006) and ISO 14044 (2006). The credibility of the carbon labels can therefore be maintained despite the fact that only climate change is assessed in the schemes.

3. The development of international GHG standards

Although environmental labelling has been available for more than several decades, carbon labelling was only available for customers from 2006. The world's first carbon label, i.e. the Carbon Reduction Label (which is now referred to as the Reducing CO_2 Label) was published by Carbon Trust in UK in 2006. It aimed to quantify the life cycle GHG emissions of products and recognize the manufacturers' commitment to reduce GHG emissions. Based on the results of the pilot scheme in 2006, Carbon Trust, in cooperation with the British Standards Institute and the Department for Environment, Food and Rural Affairs (DEFRA), developed the first carbon specific assessment standard – PAS 2050.

3.1 PAS 2050

The first version of PAS 2050 was published by the British Standards Institution on 29 Oct 2008 and included detailed requirements for the assessment of GHG emissions arising from goods and services (Sinden, 2009). The assessment standard was revised in 2011 and the scope was restricted to the assessment of GHG emissions arising from a life cycle perspective of goods and services. It established, for the first time, a uniform assessment method of GHG emissions and could be considered as a milestone in the development of carbon labelling schemes. Although PAS 2050 was built on existing life cycle assessment (LCA) guidelines, including ISO 14040:2006 and ISO 14044:2006, it was the first assessment approach in the field of GHG assessment on a product level. Other GHG assessment approaches at the same time, including ISO 14064 (ISO 14064, 2006) and WRI/WBCSD: The GHG Protocol Corporate Standard (WRI/WBCSD, 2004), were developed on an organizational level.

PAS 2050 was the first internationally consulted GHG standard. Significant clarification and simplification of existing LCA requirements (i.e. ISO 14040 and ISO 14044) were undertaken. For example, In ISO 14044, in order to conduct life cycle impact assessment, the first step would be the selection of impact categories, category indicators and characterization models (ISO 14044, 2006). PAS 2050 specified that the impact category would be global warming. The category indicators were the global warming potential (GWP) of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), perfluorocarbons (PFCs) and hydrofluorocarbons (HFCs). In addition, the characterization model was a 100-year time horizon GWP model. The specification has now been adopted as the assessment guideline in many carbon labelling schemes.

3.2 WRI/WBCSD: The GHG Protocol

WRI/WBCSD had two sets of GHG assessment standards, including the GHG Protocol at a product level (WRI/WBCSD, 2011) and the GHG Protocol Corporate Standard (WRI/WBCSD, 2004). The GHG Protocol was built on ISO 14040, ISO 14044 and PAS 2050, with the intent to provide additional specifications and guidance to facilitate a consistent quantification and public reporting of product life cycle GHG emissions (WRI/WBCSD, 2011). In the assessment processes, the GHG Protocol provided more detailed guidance compared with PAS 2050. For example, although the same threshold (1%) was proposed in the GHG Protocol, in order to justify the decision to exclude an emission source due to its insignificance in the assessment, the estimation must be based on upper limit assumptions, i.e. the most conservative case.

The GHG Protocol also provided reporting requirements of the GHG results. The final report should include basic assessment processes, including general information and scope, boundary setting, allocation, data collection and quality, uncertainty and inventory results, which is in accordance with PAS 2050. The GHG Protocol, on the other hand, provided additional reporting requirement on setting reduction target and tracking inventory changes, which could help manufacturers to continuously improve.

The GHG Protocol also encouraged the use of ratio indicators to allow informed decisions, although the reporting of the ratio indicators was optional. Table 1 provides a summary of the ratio indicators proposed by the GHG Protocol.

<Insert Table 1 here>

3.3 ISO 14067

ISO 14067 was proposed in the first ISO/TC (Technical Committee) 207 / WG (Working Group) 2 meeting in April 2008. It was developed by over 100 experts from more than 30 countries, including developing countries, such as China, Argentina and Indonesia, and received a large number of comments from international involvement. According to ISO (2009), the first draft of ISO 14067 received 578 comments on Part 1: Quantification and 184 comments on Part 2: Communication. However, due to the objection raised by some countries, ISO 14067 was published as a Technical Specification rather than an internationally recognized standard in May 2013. The Technical Specification will be reviewed by May 2016 to determine whether it will be revised, withdrawn or published as an international standard.

ISO 14067 specified principles, requirements and guidelines for the quantification and communication of the carbon footprint of products (CFPs), covering both goods and services, based on GHG emissions and removals over the life cycle of a product (ISO 14067, 2013). The standard had two main objectives. The first aim was to standardize the quantification principles and procedures to assess CFPs. A complete CFP study in ISO 14067 should include a CFP quantification process, a CFP study report based on the results from the CFP quantification and a critical review based on ISO 14044. It should be noted that the critical review in ISO 14067 is different from third party verification. A critical review process ensured that (ISO 14044, 2006):

- the methods used to carry out the LCA are consistent with the International Standard;
- the methods used to carry out the LCA are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study; and
- the study report is transparent and consistent.

Such review was only needed in the CFP quantification stage while third party verification, which was the confirmation, through provision of evidence, that specific requirements related to the CFP study and its communication had been fulfilled, should be provided if the CFP study is intended to be publicly available (ISO 14067, 2013).

In the communication stage, ISO 14067 standardized the processes and reports that should be provided if the CFP study was intended to be publicly available. The communication could take the form of a CFP external communication report, a CFP performance tracking report and a CFP declaration if the CFP was intended to be communicated in a business-to-business way. The communication could also take the form of a CFP label (i.e. carbon label), aiming for direct consumer communication. A standardized format of each communication type was also provided in ISO 14067. The processes and reports could ensure reliable comparisons of different CFPs.

3.4 The evolution of international GHG standards

A comparison of the three international GHG standards is provided in Table 2. As can be seen in Table 2, the development of international GHG standards from PAS 2050 to ISO 14067 shows that research has been shifted heavily from how GHG can be assessed to how the results of the assessment can be transparently communicated to end users to enable them to make informed decisions. Both the GHG Protocol and ISO 14067 provide reporting guidelines and templates to ensure reliable comparisons. The GHG Protocol provides additional reporting requirements on setting reduction targets and tracking inventory changes. Similarly, ISO 14067 provides four types of communication methods, including CFP label, CFP external communication report, CFP performance tracking report and CFP declaration, based on the intended objective of the communication. Direct consumer communication can only be made via CFP label. Given the increasing recognition of the use of carbon labels, ISO 14067, for the first time, provides guidance and regulation on carbon labels, which can further facilitate the development of credible and comparable carbon labels in the future.

<Insert Table 2 here>

As the aim of carbon labels is to allow customers to make informed decisions, which cannot be achieved without relevant comparisons, international GHG standards have also evolved to include comparisons in the standards. According to ISO 14067 (2013), comparisons can only be made if the carbon labels to be compared follow identical quantification and communication requirements. Even the slightest change in quantification and communication requirements can prevent comparisons. It is therefore important to establish product category rules (PCRs), which includes the life cycle stages to be included, the parameters to be covered and the way in which the parameters shall be collated and documented, for each type of building material (ISO 14067, 2013). Using PCRs to assess building materials can ensure consistency and enable comparisons of materials/products in the same product category.

One of the two most important international standards that focused on PCRs was ISO 14025, which was published in 2006 to establish principles and guidelines for developing Type III environmental declaration programs. PCRs in ISO 14025 were defined as the “set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories” (ISO 14025, 2006). The role of PCRs was to ensure that clear quantification rules were adopted so that consistency across multiple claims could be achieved (Ingwersen and Stevenson, 2012). PCRs proposed in ISO 14025 were applicable to environmental product declarations (EPDs), which presented quantitative environmental results associated with a single product. Unlike carbon labels, EPDs were multi-attribute and included all environmental impact results (Zackrisson et al., 2008). However, as climate change was one of the environmental impacts in EPDs, ISO 14025 did not restrict the use of PCRs in carbon labelling.

PCRs were being developed rapidly in the construction industry for both carbon labelling and EPDs. Several PCRs have been published to include construction products. One of the most influential groups of PCRs was the International EPD System that was initiated by the Swedish Environmental Management Council. As of March 2014, the International EPD system included 18 categories of construction products, including a variety of most commonly used construction materials such as cement, concrete, steel, wood and paint. In order to provide special guidance on the PCRs for construction products, EN 15804 was published by the European Committee for Standardization (CEN) in 2012. Similar to ISO 14067, one of the main aims of EN 15804 was to enable interested parties to compare the environmental impacts of different construction products through the development of PCRs (EN 15804, 2012). In accordance with ISO 14067, EPD and carbon labelling in EN 15804, based on a system boundary of cradle-to-gate, could not be used for comparison. Developing accredited PCRs that allow for comparison will be a future agenda in international GHG standards.

In the assessment of GHG emissions, it seems that international GHG standards tend to provide less flexibility to avoid data manipulation. All three international GHG standards are based on ISO 14040 and ISO 14044, in which flexibility is provided for organizations and countries to develop their own assessment guidelines. However, such flexibility can limit the applicability of the standards and the credibility of the environmental information (Sinden, 2009). For example, Koning et al. (2010) provided an example showing how increasing the discretion of choosing system boundaries in LCA studies can result in misleading results. Manufacturers can manipulate data in the operational stage to create “low carbon” products. Flexibility in choosing individual system boundary can harm the coherence and consistency principle. As can be seen from Table 2, although four types of system boundaries are proposed in ISO 14067, only cradle-to-grave can be adopted if the GHG results are intended to be publicly available, e.g. in the form of carbon labels, except in the following two situations (ISO 14067, 2013):

- Information on specific stages (e.g. the use and end-of-life phases) is not available and reasonable scenarios cannot be simulated; or

- There are stages that are insignificant for the GHG emissions and removals of the product.

Manufacturers of building materials, especially cement and concrete products, will be required to use cradle-to-grave other than cradle-to-gate, which is the most commonly adopted system boundary to deal with uncertainties in the use and end-of-life phases, because many recent studies have proven that the use and end-of-life phases have significant impact on the life cycle GHG emissions of construction products and appropriate simulation technologies have been well established in the building and construction industry. For example, Collins (2010) found that the carbonation of the recycled concrete was negative 136.2 kg CO2 equivalent per m^3, causing the life cycle GHG emissions of concrete to reduce by 23.6%. Excluding use and end-of-life phases in the GHG assessment procedure can either cause underestimation of GHG emissions (see Chehovits and Galehouse, 2010) or overestimation of GHG emissions (see Lagerblad, 2006). Salazar and Meil (2009) stated that due to the post-use energy recovery, wood materials have a high carbon benefit that should not be overlooked. Dodoo et al. (2009) found that the post-use stage of steel should not be excluded from its life cycle assessment due to the high carbon benefit that can be achieved from recycling. Bribián et al. (2009) also reported that many certifications do not usually consider aspects related to the life cycle of the building. At the same time, many simulation technologies have been developed in the building and construction industry to facilitate the simulation and modelling use and end-of-life phases. These include GaBi (see Loijos, 2011), SimaPro 7 (see Cass and Mukherjee, 2011), WARM (see Donalson et al., 2011) and Building Information Modelling (see Stadel et al., 2011).

4. The development of carbon labelling schemes

Since the establishment of the first carbon label in UK, many other carbon labelling schemes have been initiated. The most significant ones include: the Singapore Green Labelling Scheme (SGLS), the CO_2 Measured Label and Reducing CO_2 Label, the CarbonCounted (Canada), the CarbonFree (US) and the Hong Kong Carbon Labelling Scheme (CLS). A detailed list of currently available carbon labelling schemes for building and construction materials is shown in Table 3.

<Insert Table 3 here>

The objective of these carbon labelling schemes is similar, which is to serve as a meaningful and transparent yardstick to measure GHG emissions. Each carbon labelling scheme has its own merits and contributes to the development of a globally recognized carbon label.

4.1 Singapore Green Labelling Scheme

The SGLS was launched by the Ministry of the Environment in 1992 and was now governed by the Singapore Environment Council. In a strict sense, the SGLS is a type I ecolabelling scheme following the categorization proposed by ISO although the amount of carbon emissions will be indicated in the labels for building materials. For example, precast concrete products have to meet the two environmental prerequisites, which are the use of recycled materials and conformance to the leaching test, in order to be certified. Similarly, adhesives and sealants have to meet two prerequisites, i.e. low toxicity and no damages to the environment.

The SGLS uses accredited laboratories in Singapore to test the carbon emissions level. The LCA methods, assumptions and boundaries for different construction materials can therefore be kept consistent to ensure reliable comparisons. However, since no communication program is provided, the SGLS is not ISO 14067 compliant.

4.2 CO_2 Measured Label and Reducing CO_2 Label

The CO_2 Measured Label and Reducing CO_2 Label were introduced in the UK in 2006 by the Carbon Trust. The main LCA methods used in the labelling program include PAS 2050 and WRI/WBCSD: The GHG Protocol. Similar to the SGLS, the CO_2 Measured Label appoints an evaluation team to ensure consistency. When the LCA results pass the internal review of the Carbon Trust, the CO_2 Measured Label can be used to promote the products with the CFP indicated at the right side of the label.

The innovation in the two carbon labels is that a product emissions report should be provided along with the CFP. In the report, a summary of the company’s strategy to manage carbon across the company as a whole should be provided. If the company can provide an additional summary of the company’s objectives/targets for reducing GHG emissions, the Reducing CO_2 Label can be issued to demonstrate the companies’ commitment in reducing GHG emissions.

4.3 CarbonCounted

The CarbonCounted was established in January 2007 by CarbonCounted Carbon Footprint Solutions in Canada. It used a live carbon supply chain to determine the amount of carbon dioxide emitted to bring a product to market (CarbonCounted, 2013). Similar to other carbon labelling schemes, the CarbonCounted uses a single score to indicate the amount of carbon dioxide, although such practice is not supported by all three international GHG standards which state that all greenhouse gases should be considered and the unit of measurement is carbon dioxide equivalent. In addition, the CarbonCounted uses a unique system boundary consisting of cradle-to-gate and transportation to retail. The CarbonCounted claims that this will help manufacturers by providing useful carbon information in the supply chain and eventually help consumers to identify low carbon products.

4.4 CarbonFree

The CarbonFree labelling scheme was developed by the Washington-based Carbon Fund, an independent non-profit carbon offset provider, along with the Edinburgh Centre for Carbon Management. The labelling program was established in March 2007. Unlike the Singapore Environment Council and the Carbon Trust, Carbon Fund does not provide evaluation team or accredited laboratories to conduct the LCA study. One major difference between CarbonFree and other carbon labels is that the GHG emissions of the materials will not be indicated in the

CarbonFree label. Instead, the manufacturer should donate an amount of money which goes into third-party validated carbon offset projects. The amount of GHG emissions that is offset by the donation will be shown in the label. In other words, The CarbonFree is more related to demonstrating the manufacturers' contributions towards corporate social responsibility than to developing a meaningful yardstick to identify low-carbon products.

4.5 Hong Kong Carbon Labelling Scheme

The Hong Kong Carbon Labelling Scheme was a voluntary ecolabelling scheme launched by the Construction Industry Council and administered by Zero Carbon Building Ltd. in December 2013. It covered cement and reinforcement bars at the time of the study with 30 to 50 types of construction materials to be labelled in the future. One significant contribution of the Hong Kong Carbon Labelling Scheme is the implementation of Product Category Rule (PCR) in carbon labelling. PCR defines the goal and scope for the product category and should include the life cycle stages to be included, the parameters to be covered and the way in which the parameters should be collated and documented (ISO 14067, 2013). Reliable comparisons of different materials can be made if the materials to be compared follow the same PCR. The PCR used in the Hong Kong Carbon Labelling Scheme was developed by Environmental Product Declaration (EPD) (EPD, 2010). For cement, downstream processes including transportation from manufacturing facilities to construction sites, reuse, recycling and recovery are excluded from the labelling scheme.

4.6 The evolution of carbon labels for construction materials

Since the establishment of the first carbon label in UK, carbon labels for construction materials have been constantly evolving. The system boundaries in the carbon labels vary significantly with the SGLS using cradle-to-gate, the CarbonCounted using cradle-to-gate plus transportation to retail, the CarbonFree using cradle-to-grave and the CO_2 Measured Label and Reducing CO_2 Label using either cradle-to-gate or cradle-to-grave. Lack of a uniform standard can lead to confusion and cause difficulty for consumers to change their buying behaviour simply because they cannot compare the carbon footprints of different materials. Therefore, one major evolutionary change in the carbon labels is the adoption of product category rule to ensure that reliable comparison can be made within the same material category, as can be seen in the Hong Kong Carbon Labelling Scheme.

In addition, as the aim of carbon labelling schemes is to allow customers to make informed decisions, the use of a single sign to represent the carbon information may be problematic. According to Grant and Macdonald (2009), LCA has little to say about the adaptability of the system, its limits, risks or potential, which are all necessary information to evaluate the products' environmental compatibility. The single sign will affect the transparency principle in the international GHG standards because it is unrealistic for third parties (e.g. customers) to make associated decisions (e.g. to purchase the product or not) based on a single sign, especially for similar products with close GHG values. Therefore, another major evolutionary change in the carbon labels for construction materials is the adoption of benchmarking to ensure transparent communication. For example, Wu and Feng (2012) developed a lean benchmark for carbon labels to indicate the gap between the current and the “leanest” performance. Such benchmark offers insights on the limits of the production system and provides the improvement potential of the construction materials on carbon performance. Chau et al. (2000) also proposed the use of economic benefit-cost ratios to help reveal the potential benefit and cost of certain life cycle stages. Five benchmarks have been proposed in the Hong Kong Carbon Labelling Scheme, with Class A being the highest grade and Class E being the lowest grade.

Carbon labels have also evolved into two different types. The first type is the regular carbon label at a product level, demonstrating the life cycle GHG emissions of the products, e.g. CO_2 Measured Label and CarbonCounted. The other type, instead of presenting the life cycle GHG emissions of the products, is on a company level, demonstrating the company’s commitment in reducing GHG emissions, e.g. CarbonFree. It is very difficult to compare these two types because they serve different functions. However, it should be noted that the latter type is not within the scope of international GHG standards and there is a large research gap relating to the management of carbon labels for offsetting purposes.

5. An agenda for the future

Both international GHG standards and carbon labelling schemes will evolve in the coming years due to the recent publication of ISO 14067, although the evolution may not be instant. The publication of ISO 14067 as a technical specification at the moment shows that great differences exist among researchers and professionals in carbon labelling practices and it is not an easy road to establish a uniform GHG standard for all countries. ISO seems to be a good organization to steer the standardization process based on its great success in environmental management (ISO 14000 series) and quality management (ISO 9000 series).

Based on the evolution of international GHG standards and carbon labelling schemes, there are a few urgent issues that require immediate attention. These issues include raising consumer awareness, benchmarking, standardization and the development of appropriate simulation technologies.

5.1 Raising consumer awareness

Carbon labelling has been available for the building and construction industry since 2006. It is still in its infancy with the feasibility of carbon labelling being investigated in many countries. Researchers argue that by labelling low-carbon products, consumer buying behaviour can be changed, which will eventually increase the demand of the low-carbon products and bring economic benefits to the manufacturers who have invested a substantial amount of resources in the labelling process. This, however, has never been empirically examined in the building and construction industry where the price of materials has always been the first priority when selecting materials (Wu and Low, 2011; Wu and Low, 2012). Vanclay et al. (2011) found that the overall change in purchasing pattern after the implementation of carbon labelling was small unless the labelled materials were also the cheapest. Failure to change purchasing pattern can be disastrous to carbon labelling schemes. In 2012, Tesco, one of the largest partners of Carbon Trust in UK, decided not to feature the Reducing CO_2 Label on its products, claiming it is too time-consuming and expensive to justify (The Guardian, 2012). The reason for Tesco to cease partnership with Carbon Trust, one of the greatest pioneers in carbon labelling, is very straightforward. The costs of obtaining carbon labels for the products surpass the benefits that the carbon labels can bring. Therefore, a large research gap emerges relating to whether carbon labelling schemes can change the purchasing behaviour of consumers, e.g. clients, contractors and subcontractors, in the building and construction industry.

Other than costs, consumer awareness of carbon knowledge and carbon labels can also contribute to the success of carbon labelling schemes. Although the term "carbon labelling", along with "global climate change" and "carbon emissions", has been one of the most popular terms in the world, confusion and misapprehension still exist. For example, through a focus group study, Upham et al. (2011, p.352) found that respondents were particularly, and universally, perplexed by the measurements involved in carbon labels, with the following resultant comment:

"It's difficult. I've no idea what 260g of carbon looks like. I'm sure it's better [than the comparatively higher carbon product] but I have no idea what the impact of 260g is like. I have no idea".

It can therefore be reasonably assumed that consumers in the building and construction industry may not be fully equipped with the carbon knowledge and the tools relating to the selection of low-carbon construction materials. The problem may be caused by the development of life cycle assessment, which was originally intended for business to business communication. It is only until recently that life cycle assessment is used for direct consumer communication. Unfamiliarity with the carbon knowledge and carbon labels from consumers is a future research gap that requires immediate actions.

5.2 Benchmarking

One useful tool to help customers change their purchasing behaviour is benchmarking, which has been very commonly used in ecolabelling schemes. According to Ng et al. (2013), three types of benchmarks have been adopted in existing ecolabelling schemes. The first type of benchmarking is to award labels to products that meet a predetermined performance level. Ecolabelling schemes using such benchmarks include Energy Star (U.S.Environmental Protection Agency, 2014), Green Label Scheme (Hong Kong Green Council, 2014) and European EcoLabel (European Commission, 2014). The second type is scoring/percentage labels demonstrating the products' life cycle GHG emissions, environmental performance or their reduction potential compared to conventional production. This type of benchmarking is the most commonly adopted strategy in current carbon labelling schemes, as can be seen in the carbon labels developed by Carbon Trust (2013), the CarbonCounted (2013) and the CarbonFund (2013). Another type of benchmarking is tiered rating/grading labels to label products in different grades based on their performance. Ecolabelling schemes using such benchmarks include the Voluntary Energy Efficiency Labelling Scheme (Hong Kong Electrical and Mechanical Services Department, 2014) and the Product Certification Scheme (Singapore Green Building Council, 2014).

One evolutionary change in the development of carbon labels in the future will therefore be the implementation of different types of benchmarks. Construction materials can be categorized into “Platinum”, “Gold”, “Silver”, or “Bronze” based on their life cycle GHG emissions compared to the global average GHG emissions level. Such practice has already been initiated in the Hong Kong Carbon Labelling Scheme, which has five grades including Grade A – Outstanding; Grad B – Very Good; Grade C – Good; Grade D – Fair; and Grade E – Improvement needed. The categorizing system can offer an intuitive explanation of the products’ environmental performance against an internationally recognized benchmark, the development of which will require further standardization.

5.3 Standardization

ISO 14067 (2013) stated that even the slightest change in quantification and communication requirements can harm reliable comparisons. The development of internationally recognized benchmarks for carbon labels will therefore require high standardization. As can be seen from the Hong Kong Carbon Labelling Scheme, the benchmarks adopted are from global databases on embodied carbon, such as the Inventory of Carbon and Energy (ICE) developed by the University of Bath (UK). However, the ICE is based on a system boundary of cradle-to-gate, while the Hong Kong Carbon Labelling Scheme uses cradle-to-site to calculate the products’ carbon grade. Differences in quantification requirements can harm the credibility of the carbon labels.

Following the development of one internationally recognized GHG standard (which is the aim of ISO 14067 and its following revisions), the establishment of product category rules for different type of products will be crucial. PCRs can help reduce confusion when it comes to comparison because all materials within the same category are assessed under the same quantification procedures and assumptions. However, as product category rules were only initiated in early 2012 before the establishment of ISO 14067, PCRs should be reviewed in due course to ensure ISO 14067 compliance because some new rules regulating the use of carbon labels are proposed in ISO 14067 which contributes significantly in the aspect of standardization.

5.4 Simulation technologies in carbon labelling

One significant opportunity that ISO 14067 presents for the building and construction industry is the development of simulation technologies. Use and end-of-life phases, if proven to have considerable impact (>1%) on the life cycle GHG emissions of the products, cannot be excluded from the assessment. In fact, many recent studies have shown that the use and end-of-life phases of cement and concrete products have considerable impact on the life cycle GHG emissions (e.g. Collins, 2010; Kikuchi and Kuroda, 2011; Santero and Horvath, 2011). Similarly, the post-use energy recovery of wood and the recycling of reinforcing steel give high carbon benefits that cannot be overlooked in the life cycle of these materials (Dodoo et al., 2009). The proposition will promote the use of Building Information Modelling (BIM) or other simulation technologies to calculate the GHG emissions in a true life cycle perspective.

Various simulation technologies have been developed in the building and construction industry to modelling use and end-of-life phases for construction materials. BIM (e.g. Revit) can be used as a platform for specific analysis purposes. It can be used as a platform to conduct full-process LCA if appropriate BIM plug-ins, e.g. the Integrated Environmental Solutions' Virtual Environment Revit Plug-in, are used (see Stadel et al., 2011). GaBi, developed by PE-Internatinal, is also a life cycle assessment tool which can be used to simulate the life cycle of products. It also provides a sensitivity analysis tool in accordance with ISO 14067 to justify the decisions to exclude certain life cycle stages. Therefore, following the development of PCRs, simulation technologies may be altered in the future to meet the specifications of different product categories. As all materials in the same category will be based on the same simulation assumptions, standardization and reliable comparisons can be ensured.

6. Conclusions

Global climate change poses threats to human development and one of the most important tools for the building and construction industry to address the issue is the development of credible and transparent carbon labelling schemes based on internationally recognized GHG standards. The aim of GHG quantification is to provide useful, credible and transparent information for customers to make informed decisions. Since the establishment of PAS 2050 in 2008 in UK, international GHG standards have been evolving towards the stated aim. Additional reporting guidance and specifications relating to the use of carbon labels are provided in WRI/WBCSD: The GHG Protocol in 2011 and ISO 14067 in 2013.

In addition, a review of the development of carbon labelling schemes shows that one major evolutionary change in carbon labelling schemes is the adoption of product category rules to ensure reliable comparison within the same product category. Tiered rating/grading, which is a commonly adopted benchmarking strategy in ecolabelling schemes, have recently been adopted in carbon labelling schemes. These evolutionary changes can help improve the credibility and transparency of carbon labelling schemes.

However, carbon labelling is still in its infancy and future improvements are inevitably needed. The contribution of raising consumer awareness for the success of carbon labels should not be overlooked. The implementation of different levels of benchmarks should be further investigated to ensure reliable comparison. With the recent publication of ISO 14067, product category rules should be revised in due course to be ISO 14067 compliant. It is believed that the improved carbon labelling schemes in the future can help the building and construction industry evolve towards being a "green" industry.

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Table 1. Ratio indicators proposed in WRI/WBCSD: The GHG Protocol

Raito indicators	Functions	Examples
Time ratio	To evaluate performance over time	Ratio indicator - Yearly Ratio indicator – Base year
Category ratio	To establish a relationship between data from different categories	$\frac{\text{Value of the product}}{\text{GHG emitted}}$ or $\frac{\text{GHG emitted}}{\text{Value of the product}}$
Size ratio	To improve comparability between different sizes of businesses	$\frac{\text{GHG emitted}}{\text{Value of the company}}$
Productivity/Efficiency ratio	To express the value of a business divided by its GHG impact	$\frac{\text{Sales of the company}}{\text{GHG emitted}}$ or $\frac{\text{Production volume}}{\text{GHG emitted}}$
Intensity ratio	To express GHG impact per unit of physical activity or unit of economic output	GHG emitted per electricity generated or GHG emitted per service Or GHG emitted per sale
Percentage	A percentage indicator is a ratio between two similar issues (with the same physical unit in the numerator and the denominator)	Lean score (See Wu and Feng, 2012)

Table 2. A comparison of PAS 2050, WRI/WBCSD: The GHG Protocol and ISO 14067

GHG standards **Criteria**	**PAS 2050 (2011)**	**WRI/WBCSD: The GHG Protocol (2011)**	**ISO 14067 (2013)**
Scope	Assessment	Assessment and communication	Assessment and communication
Assessment principles	Relevance Completeness Consistency Accuracy Transparency	Relevance Completeness Consistency Accuracy Transparency	Relevance Completeness Consistency Accuracy Transparency Coherence Avoidance of double-counting Participation Fairness
System boundary	Cradle-to-gate Cradle-to-grave	Cradle-to-gate Cradle-to-grave	Cradle-to-gate Cradle-to-grave Gate-to-gate Partial CPF
Treatment of use and end-of-life phases	Can be excluded if cradle-to-gate is chosen as the system boundary.	Can be excluded if cradle-to-gate is chosen as the system boundary.	Must be included if these two phases: meet the threshold (>1%); can be appropriate simulated; and the GHG result is intended to be available in terms of carbon labels.
Reporting	Basic guidelines	Basic and additional reporting guidelines	Comprehensive guidelines

GHG standards Criteria	PAS 2050 (2011)	WRI/WBCSD: The GHG Protocol (2011)	ISO 14067 (2013)
Communication applications	3rd party verification	3rd party verification Ratio indicators Base year benchmarking GHG management/reduction report Performance measurement against internal benchmarks Performance measurement against external benchmarks	3rd party verification CFP label CFP external communication report CFP performance tracking report CFP declaration report Report template
Guidelines regarding the use of carbon labels	Not provided	Not provided	Provided
Guidelines regarding the comparisons of carbon labels	Not provided	Not provided	Provided

Table 3. Carbon labelling schemes for construction materials

Carbon Labelling Schemes	Objectives	Issuing authority and issuing year	Country of origin	Examples
Singapore Green Labelling Scheme	To endorsement consumer products and services that have less undesirable effects on the environment (Singapore Environment Council, 2010).	Singapore Environment Council; 1992	Singapore	Cement and concrete products
CO_2 Measured Label	To clearly communicate the manufacturers' achievements by accurately measuring the carbon footprints of the products (Carbon Trust, 2013).	Carbon Trust; 2006	UK	Cement
Reducing CO_2 Label	To clearly communicate the manufacturers' achievements by accurately measuring the carbon footprints of the products and demonstrate the manufacturers' commitment to reduce the carbon footprint (Carbon Trust, 2013).	Carbon Trust; 2006	UK	Cement
CarbonCounted	To determine, manage and report direct carbon footprint, as well as determine and generate product carbon footprint data for use in supply chains and/or carbon labels for products or services (CarbonCounted, 2013).	CarbonCounted; 2007	Canada	Cement and concrete products
CarbonFree	To offer a meaning and transparent way to provide environmentally-friendly, carbon neutral products to customers (CarbonFund, 2013).	Carbon Fund; 2007	USA	Cement
Hong Kong Carbon Labelling Scheme	To provide verifiable and accurate information on the carbon footprint of construction materials for the communication between clients, designers, contractors and other end users (Construction Industry Council, 2013).	Construction Industry Council; 2013	Hong Kong	Cement, steel and concrete